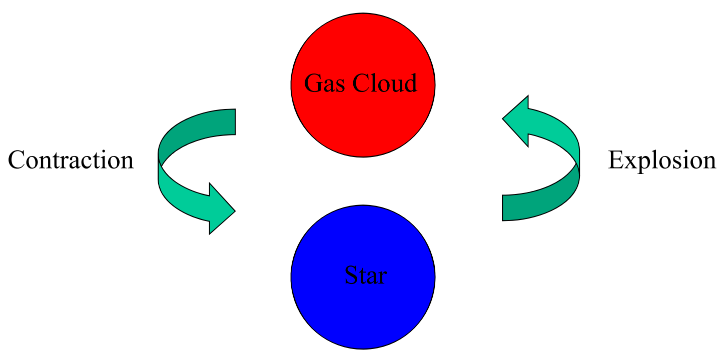
Proto-Stars

Australian Astronomical Observatory; J. Hester and P. Scowen, Arizona State University; NASA

Star or Gas?



Stellar Evolution

The energy radiated by stars comes from thermonuclear reactions, which consume hydrogen each second and convert it into helium.

The amount of hydrogen in a star is vast, but it is not infinite.

Therefore, stars must not have always been shining, nor can they continue to shine forever.

Thus, stars must have had a beginning as well as (someday) have an end.

Components of the ISM

Interstellar Gas

- H II Regions
- H I Regions

Interstellar Dust

- Reflection Nebulae
- Dark Nebulae

Giant Molecular Clouds

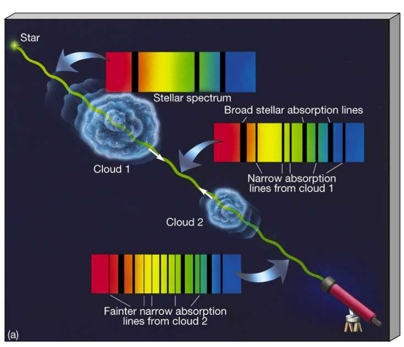
European Southern Observatory

H II Regions

W. J. MacDonald

The process for producing clouds of glowing gas near hot stars is called **fluorescence**. The light emitted from regions of ionized gas consists largely of emission lines, so they are also called **emission nebulae**.

H I Regions & Cold Clouds



Interstellar matter located at large distances from stars does not produce the strong emission lines that make H II regions visible.

A cold cloud of gas will, however, produce dark absorption lines in the spectrum of light from a star that lies behind it.

This was first seen in spectroscopic binaries, for the interstellar line does not change wavelength.

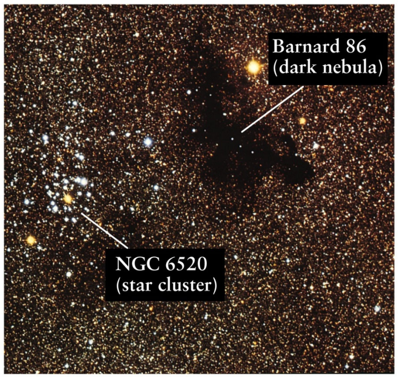
Dust

Reflection Nebulae

Some dense clouds of dust contain luminous stars within them and scatter enough starlight to become visible, which is called a reflection nebulae. Blue light is scattered more than red by the dust, so a reflection nebula usually looks bluer than the star.

Dark Nebulae

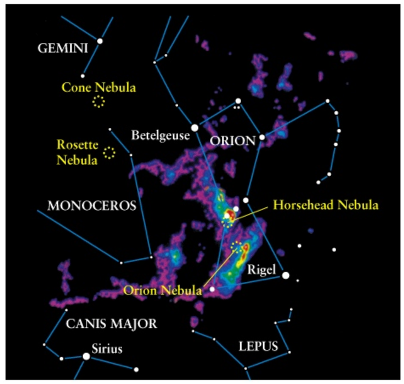
While dust clouds are invisible in the optical region of the spectrum, they glow brightly in the infrared. Small dust grains absorb optical and UV radiation very efficiently. The grains are heated by the absorbed radiation, typically to between 20 and 500 K, and reradiate this heat at IR wavelengths.



Australian Astronomical Observatory/David Malin Images

Giant Molecular Clouds

In many cases, individual clouds have gathered into large complexes containing a dozen or more discrete clumps. Since the large molecular clouds and complexes are the sites where star formation occurs, most young stars are also to be found in spiral arms.

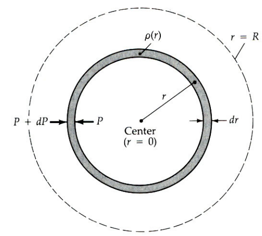


R. Maddalena, M. Morris, J. Moscowitz, and P. Thaddeus

Hydrostatic Equilibrium

What conditions must exist for star formation to begin? Sir James Jeans (1877 - 1946) first investigated this problem in 1902 by considering the effects of small deviations from hydrostatic equilibrium.

Hydrostatic Equilibrium – At each layer, the downward force of gravity is just balanced by the upward pressure of the material.



Astronomy & Astrophysics, Zeilik and Gregory

Jean’s Instability

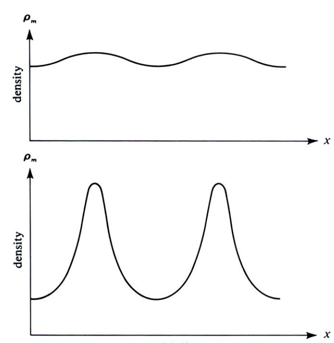


Figure 16.15. The growth of increases of matter density caused by gravitational instability was a problem first studied by Sir James Jeans. Perturbations of the type depicted in the top drawing will be unstable and grow in amplitude (after decoupling) as depicted in the bottom drawing, providing the wavelength of the disturbance exceeds 2.3 times the Jeans length defined by equation (16.12).

The Physical Universe, Shu

Proto-Star Stages

1. The initial gravitational collapse from interstellar matter is relatively quick. Once the condensation is about 1000 AU in diameter, the time for it to reach hydrostatic equilibrium is measured in thousands of years.

2. Pre-main-sequence gravitational contraction is much more gradual. From the onset of hydrostatic equilibrium to the main sequence requires millions of years. This phase of evolution can take as long as 100 million years.

These objects are not stars because their source of heat is not fusion. Rather, they are continuing to release gravitational potential energy as they shrink.

Hayashi Limit

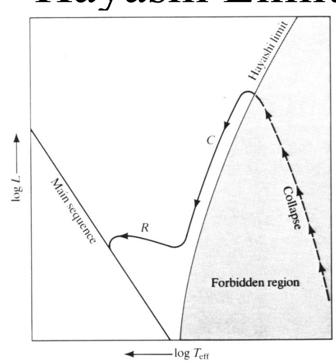


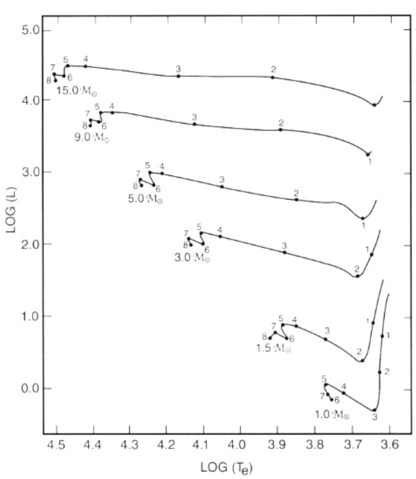
Figure 3-15. Schematic evolution track for pre-main-sequence stellar evolution. On the Hayashi track (labeled *C*) the star is convective throughout. On the portion of the track labeled *R*, the core is radiative (and, if the star is massive enough, the envelope can be radiative as well). Nuclear energy generation occurs when the star alights on the main sequence.

Galactic Structure, Mihalas and Binney

Proto-Star Stages

3. Subsequent evolution **on the main sequence** is very slow, for a star changes only as thermonuclear reactions alter its chemical composition. For a star of 1 solar mass, this gradual process requires billions of years. **All evolutionary stages are relatively faster in stars of high mass and slower in those of low mass.**

Evolutionary Tracks



Adapted from Iben, *ARAA*, 5, 571, 1967

Point	15.0 $\mathcal{M}_\odot$	9.0 $\mathcal{M}_\odot$	5.0 $\mathcal{M}_\odot$
1	6.740×10^2	1.443×10^3	2.936×10^4
2	3.766×10^3	1.473×10^4	1.069×10^5
3	9.350×10^3	3.645×10^4	2.001×10^5
4	2.203×10^4	6.987×10^4	2.860×10^5
5	2.657×10^4	7.922×10^4	3.137×10^5
6	3.984×10^4	1.019×10^5	3.880×10^5
7	4.585×10^4	1.195×10^5	4.559×10^5
8	6.170×10^4	1.505×10^5	5.759×10^5

3.0 $\mathcal{M}_\odot$	1.5 $\mathcal{M}_\odot$	1.0 $\mathcal{M}_\odot$
3.420×10^4	2.347×10^5	1.189×10^5
2.078×10^5	2.363×10^6	1.058×10^6
7.633×10^5	5.801×10^6	8.910×10^6
1.135×10^6	7.584×10^6	1.821×10^7
1.250×10^6	8.620×10^6	2.529×10^7
1.465×10^6	1.043×10^7	3.418×10^7
1.741×10^6	1.339×10^7	5.016×10^7
2.514×10^6	1.821×10^7	

Function of Mass

In general, the pre-main-sequence evolution of a star slows down as the star moves along its evolutionary track toward the main sequence.

The time for the whole evolutionary process is **highly mass-dependent**.

Stars of mass much higher than the Sun's mass reach the main sequence in a few thousand to a million years.

The Sun required millions of years; tens of millions of years are required for stars to evolve to the lower main sequence.

Not Understood

1. **Lower mass limit** – Objects under 0.08 $\mathcal{M}_\odot$ are not able to generate thermonuclear reactions. These "brown dwarfs" are technically not stars nor are they planets, for Jupiter's mass is only 0.001 $\mathcal{M}_\odot$. Many brown dwarfs should exist, but only a few candidates have been identified.

2. **Upper mass limit** – The upper mass limit is harder to calculate, but it is somewhere from 50 to 100 $\mathcal{M}_\odot$. (Stars above 30 $\mathcal{M}_\odot$ are extremely rare.) The internal pressures are so much greater than the self-gravities that these stars are blown apart from within.

Not Understood

3. **Mass distribution** – The cluster of stars that is formed contains many more low mass stars than intermediate mass ones. Likewise, there are more intermediate mass objects than high mass stars. As stellar mass increases, the number of stars per that mass decreases.

4. **Multiple stars** – About half of the protostars form gravitationally-bound binary star systems. It is believed that single stars are the only ones that can be encircled with planets.